UNIVERSITY OF MINNESOTA

ST. ANTHONY FALLS LABORATORY

Engineering, Environmental and Geophysical Fluid Dynamics

Project Report No. 589

Review and analysis of standard sump and SAFL Baffle removal efficiency performance data

Final Report

By
Jeffrey DG Marr

St. Anthony Falls Laboratory, University of Minnesota
2 Third Ave SE, Minneapolis, MN 55414

November 2019
Minneapolis, Minnesota

ACKNOWLEDGEMENTS

I would like to thank Omid Mohseni and Adam Howard for their thoughtful reviews of this report.

1. Introduction

Hydrodynamic separators (HDS) are a broad category of stormwater technologies that integrate into stormwater sump systems and provide primary removal and capture of sediment from influent stormwater. The performance of HDS technologies is typically evaluated in terms of Removal Efficiency and Washout/Scour. Removal Efficiency is defined as the performance of the HDS to remove sediment from influent stormwater, resulting in cleaner stormwater exiting the HDS. Washout/scour is an evaluation of the ability of a technology to function at higher flows and prevent re-suspension of captured sediment out of the HDS. Washout/scour is often a critical or limiting attribute of a technology. Many approaches are effective at capturing sediment at low flow conditions, however a large stormwater flow event will often generate conditions in the sump that substantially remobilize captured sediment and wash it out of the sump. For an HDS technology to perform adequately it needs to provide protection again washout/scour at high flows as well as removal efficiency over a full range of flows.

In 2010-2012, researchers at the St. Anthony Falls Laboratory, University of Minnesota developed an HDS-type technology named the SAFL Baffle. The research demonstrated that the SAFL Baffle is especially effective at reducing washout/scour in standard sumps and also is effective at improving Removal Efficiency performance of sumps. The project described here was motivated by a desire to review the sediment removal efficiency performance data from the original 2010-2012 research for standard sumps and sumps with SAFL Baffle inserts for 110-micron sand. The project was not focused on washout performance data. The original research was published in an MS thesis [1], in two Minnesota Department of Transportation reports 2011-08 and 2012-13 [2][3], and peer-reviewed journal articles [4][5]. This report is a review and re-analysis of the performance data and techniques of using dimensionless parameters presented in the original studies with specific focus on performance with 110-micron sand.

The report contains the following information:

- Technical review of original data to determine if there exists any removal efficiency data for 4-ft and 6-ft Sumps with SAFL Baffle using 110-micron sand.
- Plots of the raw data collected on sumps without SAFL Baffles.
- Plots of the raw data collected on sumps with SAFL Baffles.
- Clarification of how the testing of standard sumps in Volume 1 MnDOT report informs the sump/SAFL Baffle removal efficiencies reported in Volume 2 MnDOT report.
- Appendix with all relevant raw data in tabular format.

2. Re-analysis

SAFL-UMN maintains an archive of the original data and analyses from this body of research; this information was located and examined as part of this effort. The original research project was carried out over a number of years and led to the Master's thesis of Adam Howard in 2010. The research involved performance testing of five standard sumps as well as testing of the SAFL Baffle in two of these same sumps (e.g. a 4-ft diameter by 4-ft deep sump (4x4) and a 6-ft diameter by 3-ft deep sump (6x3)). Once the data was located, the second step of the project was to become familiar with the research, data, and analysis methods used in the study. It also involved sorting through files and determining which data and spreadsheets were the most relevant to the final outcomes of the project (many ancillary research efforts were incorporated into the project that were not published). Figure 1 is a summary plot of all the data collected in a standard sump (i.e. no SAFL Baffle) determined to be "final" and are plotted here in dimensional units. Each data point represents the removal efficiency measured for a narrow range of grainsize, sump size, and flow rate. The figure illustrates the large quantity of information generated by the researchers. It also highlights the challenge of how to make the information accessible to stakeholders such as for design or regulatory approval.

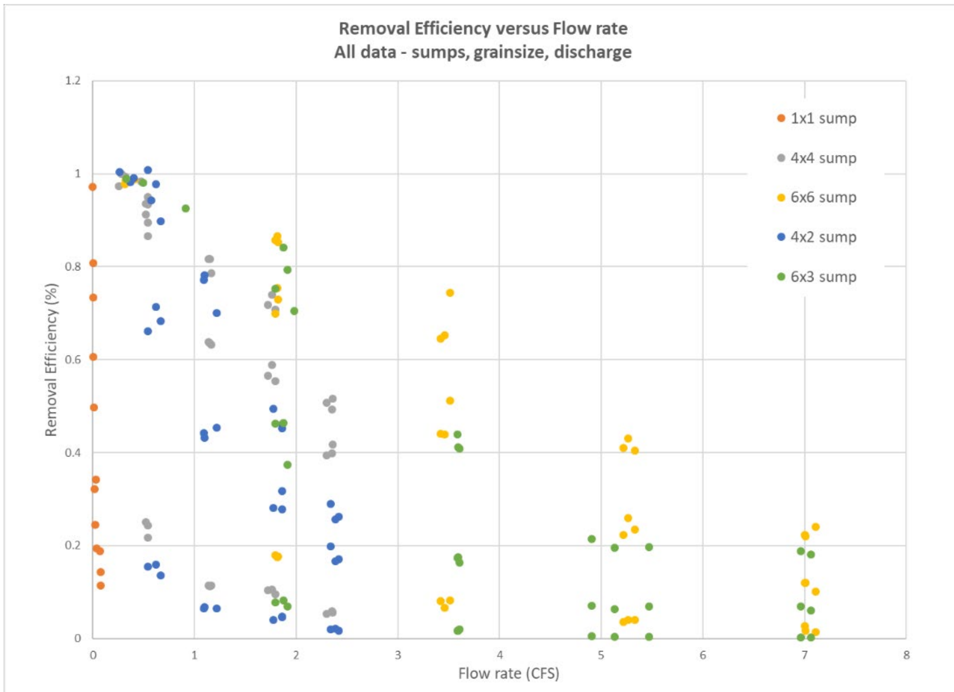

Figure 1. Plot of all "final" data generated by the research team for standard sumps plotted in dimensional units as removal efficiency versus flow rate. The dataset includes all grainsizes (110-micron, 330-micron, and 550-micron), and all standard sumps (1x1, 4x4, 6x6, 4x2, and 6x3).

3. Removal efficiency of standard sump with 110-micron sand

The research methods that led to the SAFL Baffle involved evaluating removal efficiency using narrow grainsize bands of sediment. Three bands were selected and manufactured using a large sieving apparatus at the research laboratory to create distinct size-classes of well-sorted material: 110-micron, 330-micron and 550-micron sand. Each grainsize was tested in a standard sump over a range of discharges.

The data shown in Figure 1 represent all three grainsize but it is useful to look at the performance of only 110-micron sand in the five different standard sump configurations. Figures 2, 3, and 4 show measured removal efficiency for the five standard sumps examined in the study for the 110-micron size class. In Figure 2, the 1x1-ft sump data is shown. Figure 3 includes removal efficiency data of 110-micron sand from the 4x4 and 4x2 sumps. Similarly, in Figure 4, removal efficiency data is plotted for 6x6 and 6x3 standard sumps and 110-micron sand.

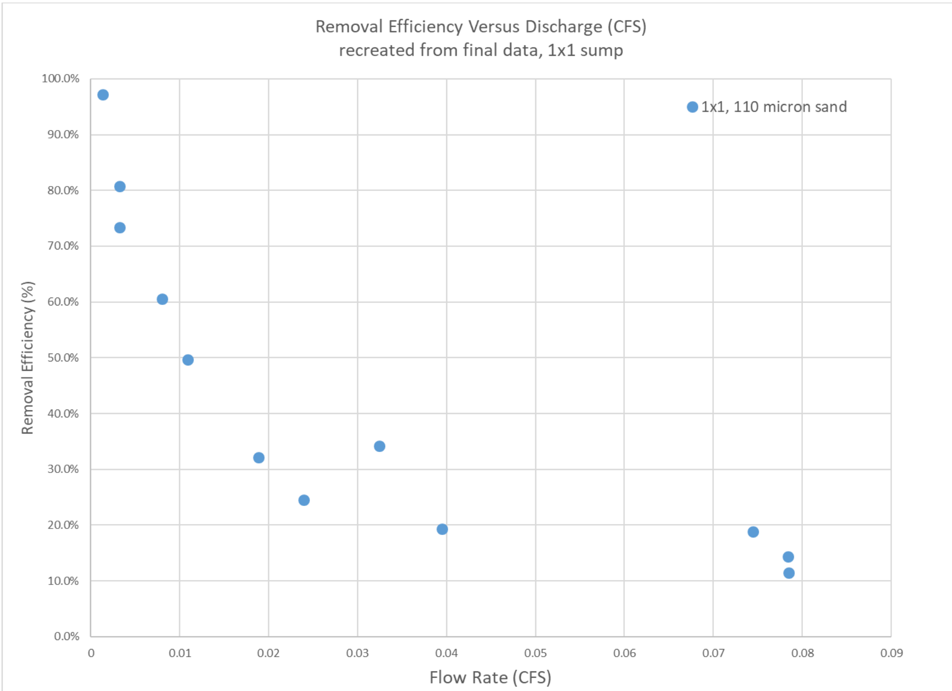

Figure 2. Summary of removal efficiency data measured for 110-micron sand in the 1x1 standard sump.

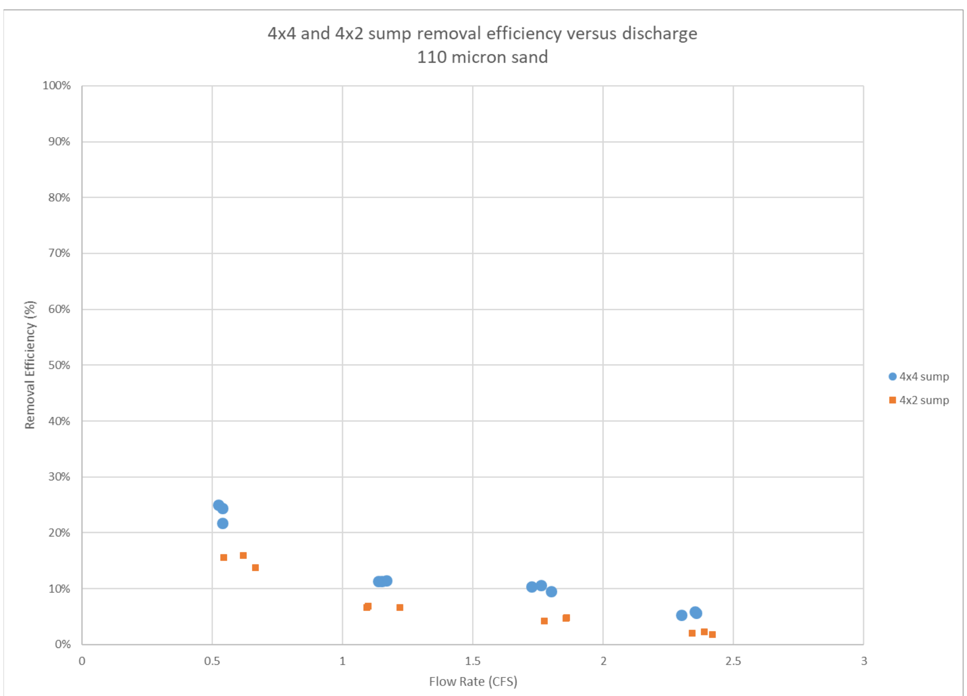

Figure 3. Plot of removal efficiency for 110-micron sand with 4-ft sumps.

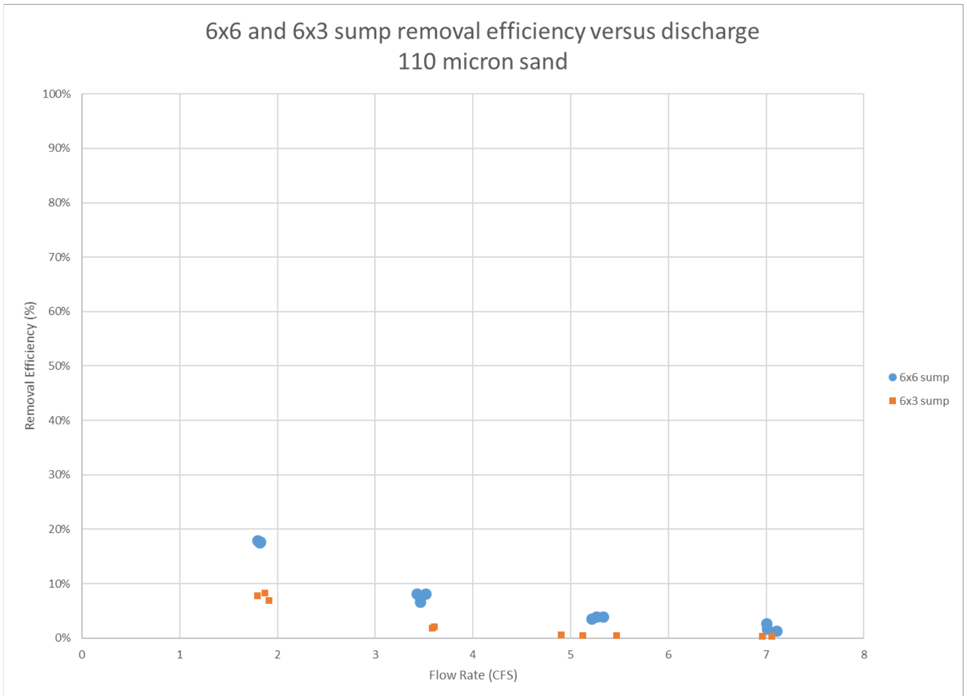

Figure 4. Plot of removal efficiency for 110-micron sand with 6-ft sumps.

One of the main motivational questions for this re-analysis of data is in regard to the 110-micron removal efficiency data shown in these three plots. The researchers chose to not evaluate removal efficiency with 110-micron sand at very small discharges and so the performance of the 4-ft and 6-ft sumps at low discharge was not explicitly measured. While it is logical that removal efficiency will increase with lower discharge and the removal efficiency must converge to 100% as discharge goes to zero, the shape of the removal efficiency versus flow rate relationship was not explicitly determined. It will be shown later that, through dimensional analysis of all data, the removal efficiency behavior at any flow rate and sediment grainsize can be estimated using non-dimensional performance curves for the hydrodynamic separators.

4. Removal efficiency with 330- and 550-micron sand

The researchers also included testing with two additional grainsizes in 4-ft and 6-ft sumps. The larger grainsizes were not tested in the 1x1 sump. The re-analysis work involved locating these data and reviewing their analyses. The figures below summarize these data and are plotted in dimensional units.

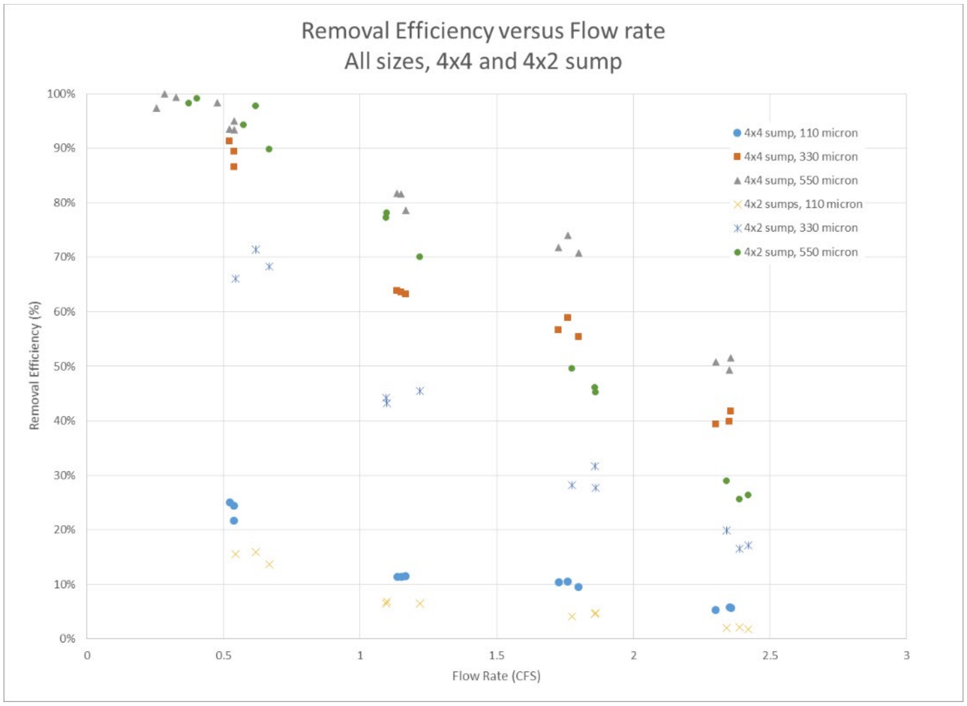

Figure 5. Summary of all data collected in 4-ft sumps for all grainsize classes.

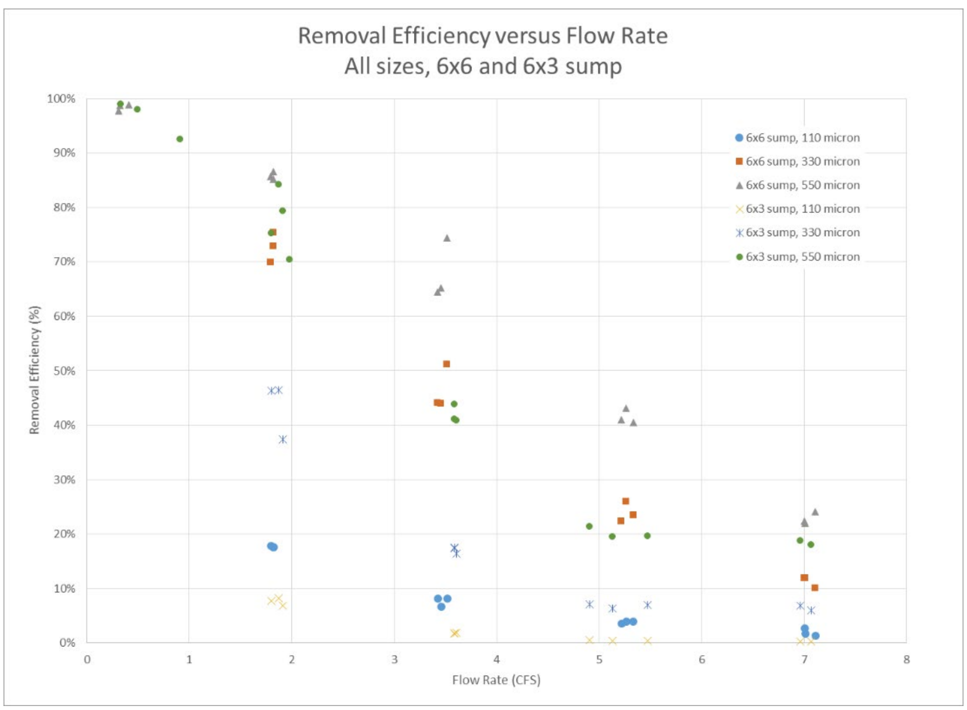

Figure 6. Summary of all data collected in 6-ft sump for all grainsize classes.

5. Non-dimensionalization of the data

An innovation offered by the original researchers was determining methods of representing the data, which span a broad range of sump configurations, grainsizes, and flow rates, into a compact and generalized form. The primary dependent variable that was measured in these tests was removal efficiency. The independent variables that were considered were: sump geometry (diameters and depths), settling velocity of particles (dependent on water viscosity, particle size, and particle density), and incoming flow rate. Additional dependent variables that came into play were water depth in the sump and incoming "jet" velocity. The researchers utilized a form of either the Peclet Number (Pe) or the ratio of Peclet to Froude (Pe/Fr^2) to collapse data into a generalized, non-dimensional form. The derivation of these dimensionless numbers is not provided here but can be found in the cited literature [1-5].

The researchers used both the Pe and Pe/Fr^2 approach to characterize removal efficiency and washout for standard sumps and standard sumps with the SAFL Baffle insert. The researchers showed that the Pe/Fr^2 approach could capture the resuspension and washout characteristics of the sumps during high flow events, in addition to the removal efficiency. For the purpose of this report, which is focusing on removal efficiency, the Peclet number is the primary non-dimensional parameter utilized. In this re-analysis, plots are created that summarize the available data as removal efficiency versus Peclet for various grainsizes and sump configurations. Figure 7 shows the removal efficiency performance for 110-micron sand within all sumps. Figures 8 and 9 show the same removal efficiency performance for all grainsizes within the 4-ft and 6-ft sumps.

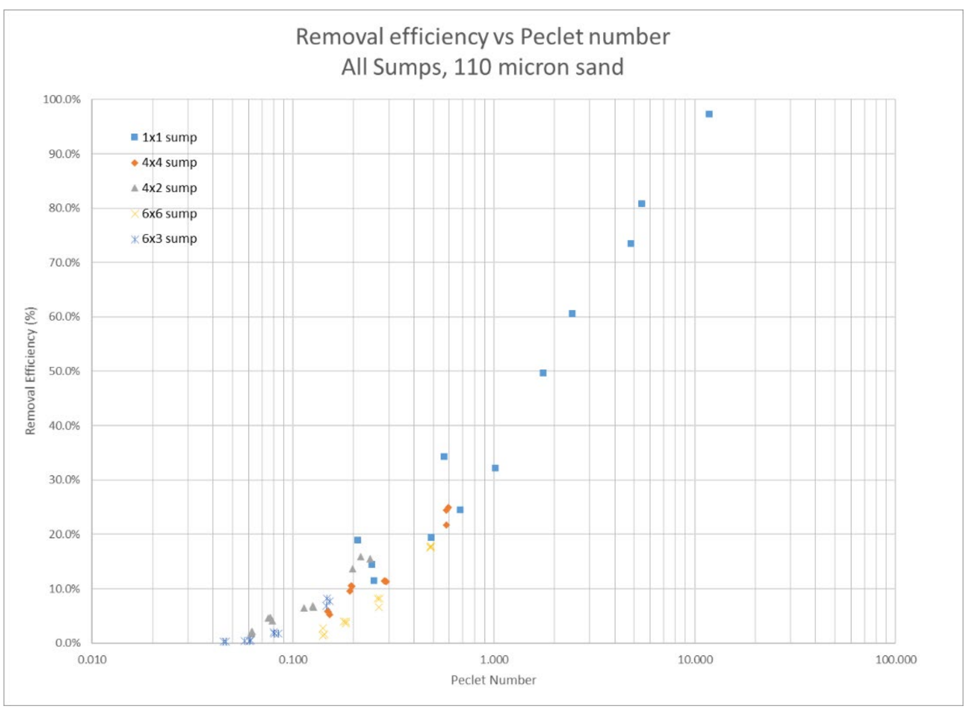

Figure 7. Plot of standard sump removal efficiency data for 110 micron sand (for all standard sump configurations) plotted as Removal Efficiency vs Peclet Number.

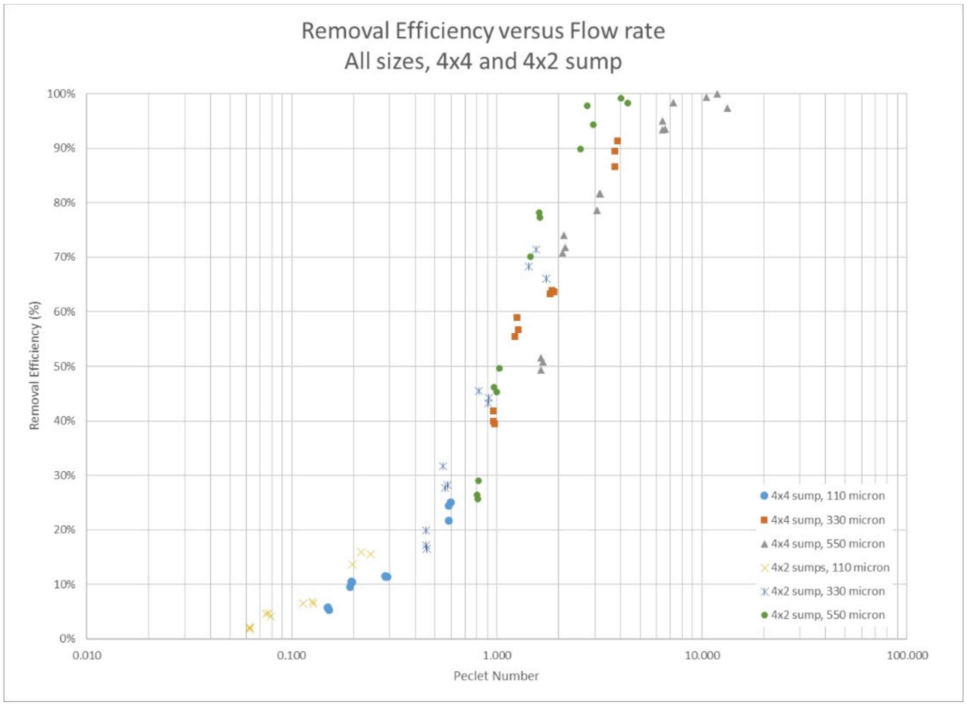

Figure 8. Plot of all 4-ft standard sump removal efficiency data plotted as Removal Efficiency vs Peclet Number.

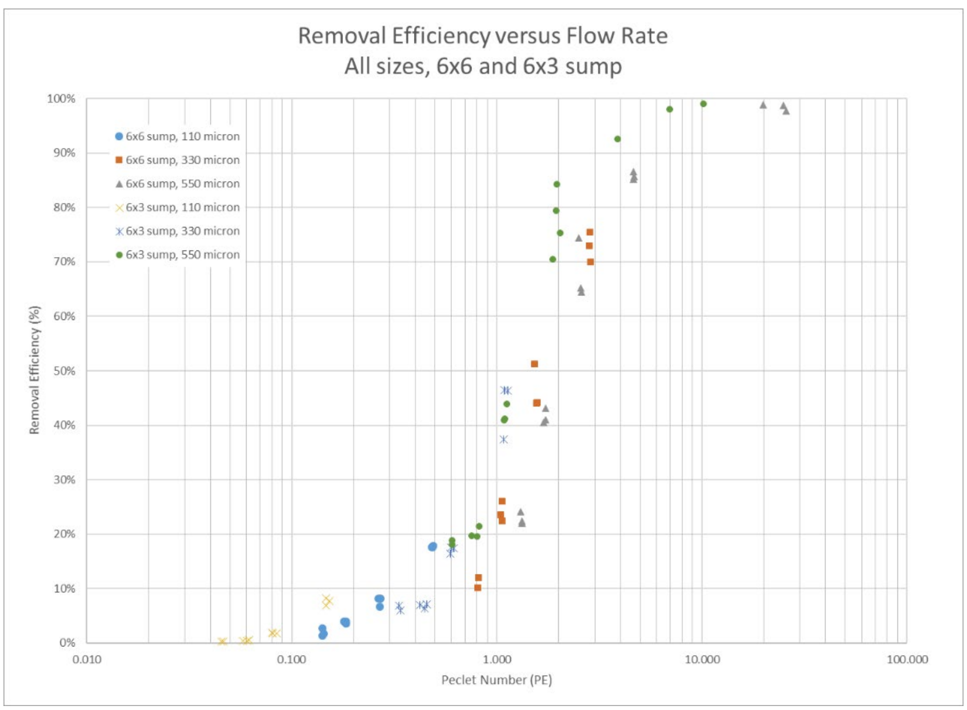

Figure 9. Plot of all 6-ft standard sump removal efficiency data plotted as Removal Efficiency vs Peclet Number.

6. Removal efficiency of sumps with SAFL Baffle

The second phase of the original research (MnDOT Report Volume 2) focused on the development and performance evaluation of a sump with SAFL Baffle insert. The SAFL Baffle is a heavy-duty, porous screen that is vertically oriented orthogonal to incoming flow in the sump. The SAFL Baffle's primary purpose is to dissipate the energy of the incoming flow and minimize the scour and washout of sediment that has been trapped within the sump. The SAFL Baffle has been shown to improve the removal efficiency performance of the sump [3].

In the re-analysis work presented here, data from the two tests that examined SAFL Baffle performance were located and reviewed. Figure 10 is a summary of the data collected from the 4x4 sump with SAFL Baffle, plotted for all grainsizes and in dimensional units. Figure 11 is a similar plot for the 6x3 sump with SAFL Baffle. The researchers chose to not evaluate sediment removal efficiency with 110-micron sand at lower discharges in the 4x4-ft and 6x3-ft sumps and so the performance of the SAFL Baffle at these discharges were not explicitly measured. However, lower discharge (and subsequent higher removal efficiencies) were tested on sumps without SAFL Baffles, as shown in Figure 2. In addition, it is logical that removal efficiency will increase with lower discharge and the removal efficiency must converge to 100% as discharge goes to zero.

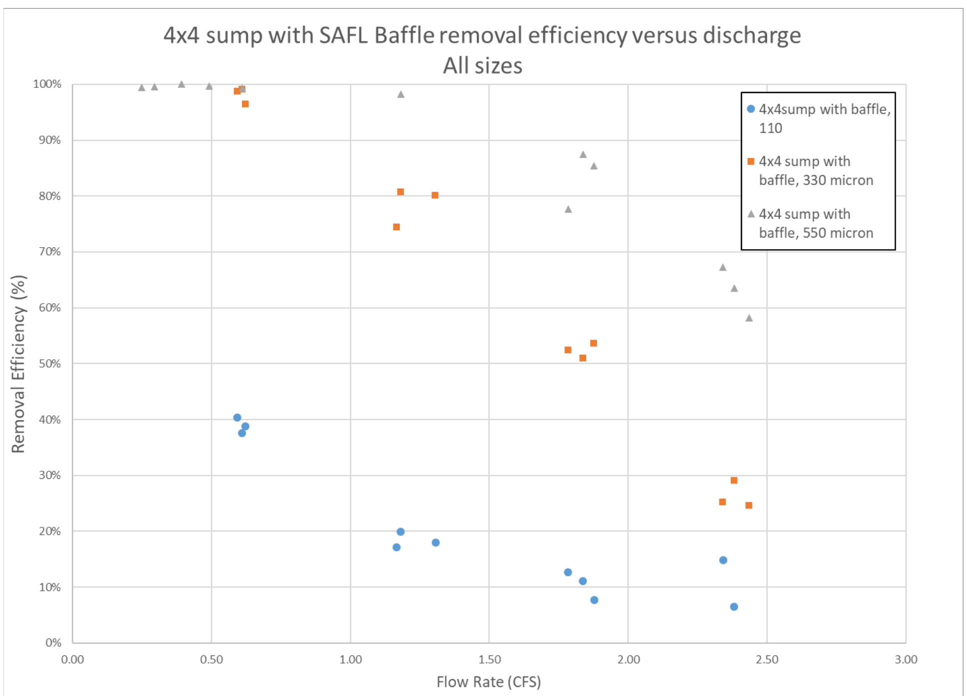

Figure 10. Summary of removal efficiency data collected for 4x4 sump with SAFL Baffle for all grainsizes. Plotted as Removal Efficiency versus flow rate.

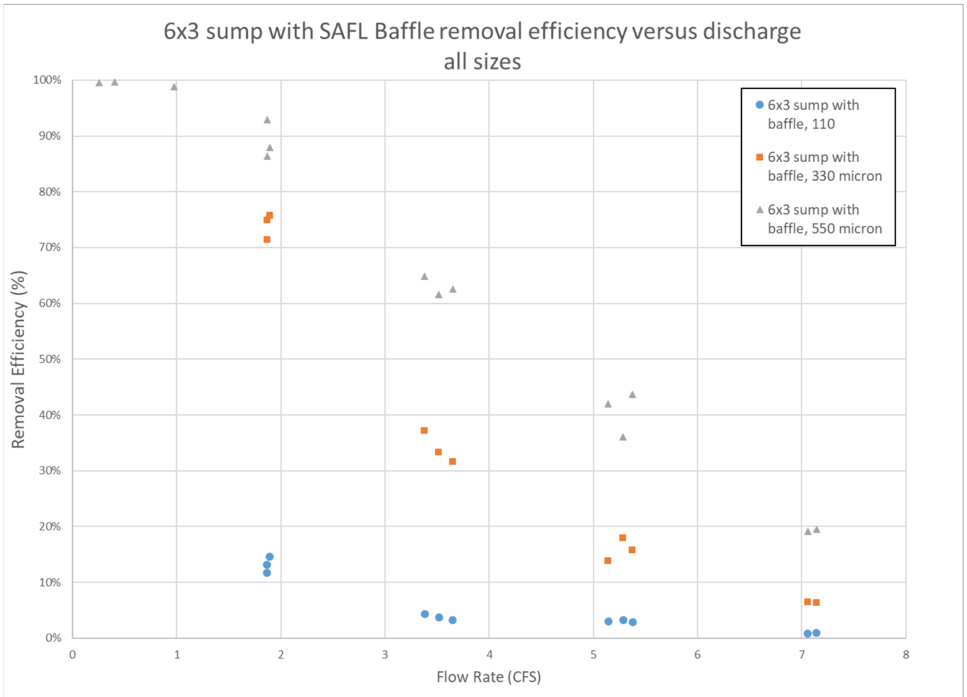

Figure 11. Summary of removal efficiency data collected for 6x3 sump with SAFL Baffle for all grainsizes. Plotted as Removal Efficiency versus flow rate.

An important outcome of the original research program, which is not readily clear from the Volume 1 and Volume 2 publications is how the research and dimensional analysis of the standard sump impacted the research on the SAFL Baffle [2][3]. The research program presented in Volume 1 involved detailed testing on five different standard sumps over a range of flow rates and grainsizes; nearly 200 individual tests were conducted. The dimensional analysis of the data resulted in identifying the Peclet Number and ratio of Peclet over the Froude Number square as the most appropriate means for generalizing the data (Figures 7, 8, and 9).

Using this verified method of dimensional analysis developed for sumps, the researchers apply the same approach to removal efficiency performance of the sump with SAFL Baffle. The knowledge that Peclet number worked so effectively for hydrodynamic separators enabled the researchers to limit their study to two sumps with the SAFL Baffle and develop a characteristic curve from these data (Figure 12).

Figure 12 is the same data from Figures 10 and 11 in non-dimensional form, plotted as removal efficiency versus Peclet Number. It is clear that the data, which spans a broad range of flow and performance in dimensional space, collapses to a single characteristic form when plotted as removal efficiency versus Peclet Number. A performance function can be fit to this data and represents the expected performance curve of the SAFL Baffle.

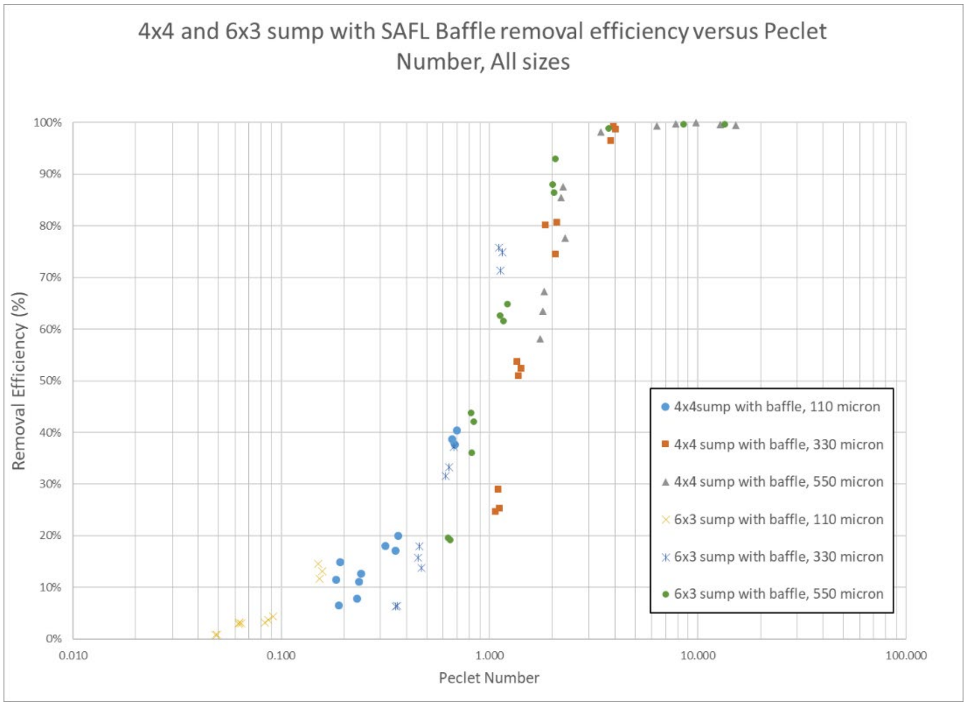

Figure 12. Summary of removal efficiency data collected for 4x4 and 6x3 sumps with SAFL Baffle for all grainsizes. Plotted as Removal Efficiency versus Peclet Number.

7. Example calculation using performance curves

The non-dimensionalization techniques and resulting performance curves can be used in a "predictive mode" to forecast the performance of a sump or sump with SAFL Baffle for conditions that were not explicitly tested in a controlled test. For example, we can use the performance information to estimate the flow rates needed to achieve 80% removal efficiency of 110-micron sand in a 4x4 sump with SAFL Baffle. The calculation is as follows:

- Using the performance curve developed for the SAFL Baffle (Figure 12), 80% removal efficiency corresponds to a Peclet number of ~2.1.
- The expression for Peclet is:

$$PE = \frac{U_S * h * D}{Q} \qquad (1)$$

Where,

U_s is the particle settling velocity,

h, is the water depth in the sump,

D, is the sump diameter,

Q, is the volumetric flow rate into the sump,

- Equation 1 can be re-arranged to solve for Q:

$$Q = \frac{U_S * h * D}{PE} \quad (2)$$

- U_s for 110-micron sand, computed using the approach outlined in [1][2] and [5], yields a settling velocity of 0.007 m/s.
- *D* is determined from sump geometry and for the sump used in the study is 1.2 m.
- *h* varies with the volumetric flow rate entering the sump and is determined through hydraulic evaluation of the sump (e.g. developing a rating curve for flow and depth in the sump). For the 4x4 -ft sump with SAFL Baffle used in this study, rating curves are used to iteratively determine sump depth, which is 1.3 meters.

Solving Equation 2 using the calculated values, a volumetric flow rate of **5.2 liters per second (0.18 cubic feet per second) is the flow rate that is predicted to yield 80% removal efficiency for 110-micron sand sized material in a 4x4 Sump with SAFL Baffle.**

8. Numerical tool - Sizing Hydrodynamic Separators and Manholes (SHSAM)

The prediction methods outlined in Section 7 are the basis for the numerical tool developed by O. Mohseni of Barr Engineering Company. The tool, Sizing Hydrodynamic Separators and Manholes (SHSAM), is a computer program for predicting the amount of sediment removed from stormwater runoff by a given hydrodynamic separator/standard sump over a given period of time, e.g. 15 years. SHSAM extends the characteristic performance curve for a range of HDS technologies (and generic sumps) and combines this with a simple continuous runoff model to estimate removal efficiency.

The numerical tool can be downloaded here: https://www.barr.com/WhatsNew/SHSAM/SHSAMapp.asp

9. Conclusion

The preceding sections provide a summary of the data collected during the original research project, which was published in several documents including MnDOT reports, a thesis and peer-reviewed journal articles. These data and important calculations have been reviewed. New plots were generated and presented here to better communicate the data availability and findings. Much of the original published research examined the washout performance of the SAFL Baffle, which is strong attribute of the technology, however the washout performance is not the focus of this project. The following observations are made:

- Removal efficiency performance data for 110-micron size particles were collected from all five standard sump sizes. However, for all sumps larger than the 1x1, low flow rate tests were not performed and removal efficiency performance greater than 30% were not explicitly documented. Removal efficiencies in the 1x1 sump were documented at near 100% for low flows.
- It is logical to assume that both 4-ft and 6-ft sumps are capable of removal efficiencies greater than 80% for 110-micron sand, however the corresponding flow rates to achieve this performance are not explicitly measured but can be predicted using dimensionless parameters outlined in the research.
- Considering Figure 1, it is clear that a vast range of performance data were collected representing five different standard sump configurations, three well-sorted grainsizes and a range of flow rates.

From the perspective of sump design or performance verification, it can be a challenge to find a simple method to utilize these results because they span such a wide range of conditions.

- The dimensionless parameters proposed by the original researchers is an elegant way of collapsing the data into generalized performance behavior. The approach is founded in well-established non-dimensional techniques from the fields of fluid dynamics and hydraulics and applied here to stormwater hydrodynamic separators.
- The dimensionless parameters collapse the data into characteristic curves plotted as removal efficiency versus Peclet number. An alternative approach uses the ratio of Peclet over the Froude number (PE/Fr^2). Figures 7, 8 and 9 show the same data cast into the form of RE vs PE and provide a more useful form for considering the performance data.
- In a second phase of research, the removal efficiency performance of two sumps with SAFL Baffles was evaluated – 4x4 and 6x3 sumps. The same dimensionless parameters were applied to these data resulting in a characteristic performance curve for the SAFL Baffle. (Figure 12).

REFERENCES

[1] Howard, Adam Keith. (2010). Use of standard sumps for suspended sediment removal from stormwater. Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/93160.

[2] Mohseni, Omid. (2011). Assessment and Recommendations for the Operation of Standard Sumps as Best Management Practice for Stormwater Treatment (Volume 1). Minnesota Department of Transportation. Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/112919.

[3] McIntire, Kurtis D.; Howard, Adam; Mohseni, Omid; Gulliver, John S. (2012). Assessment and Recommendations for Operation of Standard Sumps as Best Management Practices for Stormwater Treatment (Volume 2). Minnesota Department of Transportation. Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/167969.

[4] Wilson, M., O. Mohseni, J. Gulliver, R. Hozalski, and H. Stefan. "Assessment of Hydrodynamic Separators for Stormwater Treatment. *Journal of Hydraulic Engineering*. 131(5). 2009.

[5] Howard, A.K, Mohseni, O., Gulliver, J.S., Stefan, H.G., Hydraulic Analysis of Suspended Sediment Removal from Storm Water in a Standard Sump. Journal of Hydraulic Engineering, Vol. 138, Issue 6 (June 2012).

APPENDIX A – FINAL DATA FROM STANDARD SUMPS

The following table includes a summary of all “final” data collected in the study for standard sumps.

Original Data: Standard Sump and SAFL Baffle

Sump Size	Removal Efficiency (%)	Particle Size (mm)	Flowrate (cfs)	Flowrate (m3/s)	Settling Velocity (m/s)	Peclet Number (-)
1x1	97%	0.107	0.001	0.00004	0.005345001	11.82
1x1	81%	0.107	0.003	0.00009	0.005674449	5.45
1x1	73%	0.107	0.003	0.00009	0.00511485	4.84
1x1	61%	0.107	0.008	0.00023	0.006297718	2.46
1x1	50%	0.107	0.011	0.00031	0.006087263	1.76
1x1	32%	0.107	0.019	0.00054	0.006027591	1.02
1x1	24%	0.107	0.024	0.00068	0.005059895	0.68
1x1	34%	0.107	0.032	0.00092	0.005479919	0.57
1x1	19%	0.107	0.039	0.00112	0.005802908	0.49
1x1	11%	0.107	0.078	0.00222	0.00561648	0.25
1x1	14%	0.107	0.078	0.00222	0.005494218	0.25
1x1	19%	0.107	0.074	0.00211	0.004384501	0.21
4x4	25%	0.107	0.523	0.01481	0.005400814	0.59
4x4	22%	0.107	0.539	0.01526	0.005416589	0.58
4x4	24%	0.107	0.539	0.01526	0.005432387	0.58
4x4	11%	0.107	1.136	0.03217	0.005440295	0.29
4x4	11%	0.107	1.150	0.03256	0.005712433	0.29
4x4	11%	0.107	1.167	0.03305	0.005688175	0.29
4x4	10%	0.107	1.726	0.04888	0.005519683	0.20
4x4	11%	0.107	1.760	0.04984	0.005567583	0.19
4x4	10%	0.107	1.799	0.05094	0.005599624	0.19
4x4	5%	0.107	2.301	0.06516	0.005583593	0.15
4x4	6%	0.107	2.352	0.06660	0.005575585	0.15
4x4	6%	0.107	2.357	0.06674	0.005623711	0.15
4x4	91%	0.336	0.523	0.01481	0.03523114	3.88
4x4	87%	0.336	0.539	0.01526	0.035291094	3.78
4x4	89%	0.336	0.539	0.01526	0.035350995	3.78
4x4	64%	0.336	1.136	0.03217	0.035380925	1.86
4x4	64%	0.336	1.150	0.03256	0.036389964	1.90
4x4	63%	0.336	1.167	0.03305	0.036301638	1.82
4x4	57%	0.336	1.726	0.04888	0.035679465	1.27
4x4	59%	0.336	1.760	0.04984	0.035857904	1.25
4x4	55%	0.336	1.799	0.05094	0.035976569	1.23
4x4	39%	0.336	2.301	0.06516	0.035917266	0.98
4x4	40%	0.336	2.352	0.06660	0.035887593	0.96
4x4	42%	0.336	2.357	0.06674	0.036065409	0.96
4x4	97%	0.545	0.255	0.00722	0.060329827	13.29
4x4	100%	0.545	0.286	0.00810	0.060226419	11.86
4x4	99%	0.545	0.326	0.00923	0.060329827	10.49
4x4	98%	0.545	0.477	0.01351	0.060226419	7.24
4x4	94%	0.545	0.523	0.01481	0.059914542	6.60
4x4	93%	0.545	0.539	0.01526	0.059984061	6.43
4x4	95%	0.545	0.539	0.01526	0.060053459	6.42
4x4	82%	0.545	1.136	0.03217	0.060088112	3.17

Sump Size	Removal Efficiency (%)	Particle Size (mm)	Flowrate (cfs)	Flowrate (m3/s)	Settling Velocity (m/s)	Peclet Number (-)
4x4	82%	0.545	1.150	0.03256	0.06124787	3.20
4x4	79%	0.545	1.167	0.03305	0.061147002	3.07
4x4	72%	0.545	1.726	0.04888	0.060432958	2.16
4x4	74%	0.545	1.760	0.04984	0.060638382	2.12
4x4	71%	0.545	1.799	0.05094	0.060774707	2.08
4x4	51%	0.550	2.301	0.06516	0.061273295	1.67
4x4	49%	0.550	2.352	0.06660	0.061239156	1.64
4x4	52%	0.550	2.357	0.06674	0.061443519	1.64
6x6	18%	0.107	1.797	0.05089	0.006790762	0.49
6x6	18%	0.107	1.818	0.05148	0.006833595	0.49
6x6	18%	0.107	1.821	0.05157	0.006816456	0.48
6x6	8%	0.107	3.424	0.09696	0.006928	0.27
6x6	7%	0.107	3.458	0.09792	0.006979585	0.27
6x6	8%	0.107	3.515	0.09953	0.006962383	0.26
6x6	4%	0.107	5.217	0.14773	0.006979585	0.18
6x6	4%	0.107	5.262	0.14900	0.00705707	0.18
6x6	4%	0.107	5.332	0.15099	0.006988188	0.18
6x6	3%	0.107	7.002	0.19828	0.007082925	0.14
6x6	2%	0.107	7.011	0.19853	0.007186459	0.14
6x6	1%	0.107	7.107	0.20125	0.007151929	0.14
6x6	70%	0.336	1.797	0.05089	0.040029303	2.87
6x6	75%	0.336	1.818	0.05148	0.040163301	2.85
6x6	73%	0.336	1.821	0.05157	0.040109771	2.84
6x6	44%	0.336	3.424	0.09696	0.040456052	1.57
6x6	44%	0.336	3.458	0.09792	0.040614539	1.56
6x6	51%	0.336	3.515	0.09953	0.040561805	1.54
6x6	22%	0.336	5.217	0.14773	0.040614539	1.07
6x6	26%	0.336	5.262	0.14900	0.040850668	1.06
6x6	23%	0.336	5.332	0.15099	0.040640871	1.04
6x6	12%	0.336	7.002	0.19828	0.040928947	0.82
6x6	12%	0.336	7.011	0.19853	0.041239894	0.82
6x6	10%	0.336	7.107	0.20125	0.041136632	0.81
6x6	98%	0.545	0.314	0.00889	0.065736303	25.80
6x6	99%	0.545	0.323	0.00915	0.065678841	25.02
6x6	99%	0.545	0.411	0.01164	0.065964756	19.84
6x6	86%	0.545	1.797	0.05089	0.065301943	4.69
6x6	87%	0.545	1.818	0.05148	0.0654476	4.65
6x6	85%	0.545	1.821	0.05157	0.065389442	4.63
6x6	41%	0.545	5.217	0.14773	0.065936322	1.73
6x6	43%	0.545	5.262	0.14900	0.066190981	1.72
6x6	40%	0.545	5.332	0.15099	0.065964756	1.69
6x6	22%	0.545	7.002	0.19828	0.066275241	1.32
6x6	22%	0.545	7.011	0.19853	0.066609151	1.32
6x6	24%	0.545	7.107	0.20125	0.066498404	1.31
6x6	65%	0.550	3.424	0.09696	0.066335579	2.58
6x6	65%	0.550	3.458	0.09792	0.066506971	2.56
6x6	74%	0.550	3.515	0.09953	0.06644998	2.52

Sump Size	Removal Efficiency (%)	Particle Size (mm)	Flowrate (cfs)	Flowrate (m3/s)	Settling Velocity (m/s)	Peclet Number (-)
4x2	16%	0.107	0.545	0.01543	0.004164209	0.24
4x2	16%	0.107	0.619	0.01753	0.004251893	0.22
4x2	14%	0.107	0.667	0.01889	0.004117546	0.20
4x2	7%	0.107	1.095	0.03101	0.004184326	0.13
4x2	7%	0.107	1.099	0.03112	0.004164209	0.13
4x2	7%	0.107	1.220	0.03455	0.004124188	0.11
4x2	4%	0.107	1.775	0.05026	0.004031919	0.08
4x2	5%	0.107	1.859	0.05264	0.004104285	0.08
4x2	5%	0.107	1.862	0.05273	0.004110911	0.08
4x2	2%	0.107	2.342	0.06632	0.004045005	0.06
4x2	2%	0.107	2.389	0.06765	0.004091056	0.06
4x2	2%	0.107	2.421	0.06856	0.004124188	0.06
4x2	66%	0.336	0.545	0.01543	0.030038313	1.74
4x2	71%	0.336	0.619	0.01753	0.030442169	1.56
4x2	68%	0.336	0.667	0.01889	0.0298209	1.43
4x2	44%	0.336	1.095	0.03101	0.030131504	0.91
4x2	43%	0.336	1.099	0.03112	0.030038313	0.91
4x2	45%	0.336	1.220	0.03455	0.029851955	0.82
4x2	28%	0.336	1.775	0.05026	0.029417348	0.57
4x2	32%	0.336	1.859	0.05264	0.029758794	0.54
4x2	28%	0.336	1.862	0.05273	0.029789846	0.56
4x2	20%	0.336	2.342	0.06632	0.029479409	0.45
4x2	17%	0.336	2.389	0.06765	0.029696695	0.45
4x2	17%	0.336	2.421	0.06856	0.029851955	0.45
4x2	100%	0.545	0.264	0.00748	0.054	5.93
4x2	98%	0.545	0.373	0.01056	0.054039302	4.37
4x2	99%	0.545	0.403	0.01141	0.054078125	4.05
4x2	101%	0.545	0.545	0.01543	0.053650003	3.11
4x2	94%	0.545	0.574	0.01625	0.054	2.96
4x2	98%	0.545	0.619	0.01753	0.05415571	2.77
4x2	90%	0.545	0.667	0.01889	0.053376364	2.56
4x2	77%	0.545	1.095	0.03101	0.053766996	1.63
4x2	78%	0.545	1.099	0.03112	0.053650003	1.62
4x2	70%	0.545	1.220	0.03455	0.053415511	1.47
4x2	50%	0.545	1.775	0.05026	0.052865811	1.03
4x2	46%	0.545	1.859	0.05264	0.053298014	0.97
4x2	45%	0.545	1.862	0.05273	0.053337198	1.00
4x2	29%	0.545	2.342	0.06632	0.052944552	0.81
4x2	26%	0.545	2.389	0.06765	0.053219592	0.81
4x2	26%	0.545	2.421	0.06856	0.053415511	0.80
6x3	8%	0.107	1.799	0.05094	0.003876132	0.15
6x3	8%	0.107	1.875	0.05309	0.003883111	0.15
6x3	7%	0.107	1.915	0.05423	0.003936084	0.15
6x3	2%	0.107	3.588	0.10160	0.004045005	0.08
6x3	2%	0.107	3.590	0.10166	0.003852099	0.08
6x3	2%	0.107	3.609	0.10220	0.003848946	0.08
6x3	0%	0.107	4.907	0.13895	0.003901556	0.06

Sump Size	Removal Efficiency (%)	Particle Size (mm)	Flowrate (cfs)	Flowrate (m3/s)	Settling Velocity (m/s)	Peclet Number (-)
6x3	0%	0.107	5.130	0.14527	0.003939293	0.06
6x3	0%	0.107	5.472	0.15495	0.004007145	0.06
6x3	0%	0.107	6.962	0.19714	0.003898371	0.05
6x3	0%	0.107	7.065	0.20006	0.004021474	0.05
6x3	46%	0.336	1.799	0.05094	0.028667427	1.13
6x3	46%	0.336	1.875	0.05309	0.028701465	1.09
6x3	37%	0.336	1.915	0.05423	0.028958462	1.08
6x3	17%	0.336	3.588	0.10160	0.029479409	0.62
6x3	18%	0.336	3.590	0.10166	0.028549887	0.60
6x3	16%	0.336	3.609	0.10220	0.028534427	0.59
6x3	7%	0.336	4.907	0.13895	0.028791226	0.45
6x3	6%	0.336	5.130	0.14527	0.028973952	0.44
6x3	7%	0.336	5.472	0.15495	0.029299461	0.42
6x3	7%	0.336	6.962	0.19714	0.028775747	0.33
6x3	6%	0.336	7.065	0.20006	0.029367706	0.34
6x3	99%	0.545	0.330	0.00934	0.05292881	10.23
6x3	98%	0.545	0.494	0.01399	0.05247504	6.96
6x3	93%	0.545	0.912	0.02583	0.052138243	3.88
6x3	75%	0.545	1.799	0.05094	0.051907775	2.04
6x3	84%	0.545	1.875	0.05309	0.051951525	1.97
6x3	79%	0.545	1.915	0.05423	0.052281028	1.94
6x3	70%	0.545	1.980	0.05607	0.052324616	1.88
6x3	21%	0.545	4.907	0.13895	0.052066775	0.82
6x3	20%	0.545	5.130	0.14527	0.052300843	0.80
6x3	20%	0.545	5.472	0.15495	0.052716014	0.76
6x3	19%	0.545	6.962	0.19714	0.052046913	0.60
6x3	18%	0.545	7.065	0.20006	0.052802769	0.61
6x3	44%	0.550	3.588	0.10160	0.053495475	1.12
6x3	41%	0.550	3.590	0.10166	0.052303877	1.10
6x3	41%	0.550	3.609	0.10220	0.052283895	1.09
4x2 with baffle	40%	0.107	0.593	0.01679	0.007100169	0.70
4x2 with baffle	38%	0.107	0.611	0.01730	0.007117417	0.68
4x2 with baffle	39%	0.107	0.623	0.01764	0.007031228	0.66
4x2 with baffle	17%	0.107	1.167	0.03304	0.006799325	0.35
4x2 with baffle	20%	0.107	1.181	0.03344	0.007022617	0.36
4x2 with baffle	18%	0.107	1.307	0.03701	0.006816456	0.32
4x2 with baffle	13%	0.107	1.784	0.05052	0.006842168	0.24
4x2 with baffle	11%	0.107	1.837	0.05202	0.006893644	0.24
4x2 with baffle	8%	0.107	1.877	0.05315	0.006876478	0.23
4x2 with baffle	15%	0.107	2.342	0.06632	0.006970983	0.19
4x2 with baffle	7%	0.107	2.381	0.06742	0.006919408	0.19
4x2 with baffle	11%	0.107	2.435	0.06895	0.006910818	0.18
4x2 with baffle	99%	0.336	0.593	0.01679	0.040981013	4.04
4x2 with baffle	99%	0.336	0.611	0.01730	0.041032983	3.94
4x2 with baffle	96%	0.336	0.623	0.01764	0.040772173	3.83
4x2 with baffle	74%	0.336	1.167	0.03304	0.040056149	2.09
4x2 with baffle	81%	0.336	1.181	0.03344	0.04074596	2.11

Sump Size	Removal Efficiency (%)	Particle Size (mm)	Flowrate (cfs)	Flowrate (m3/s)	Settling Velocity (m/s)	Peclet Number (-)
4x2 with baffle	80%	0.336	1.307	0.03701	0.040109771	1.86
4x2 with baffle	52%	0.336	1.784	0.05052	0.040190031	1.42
4x2 with baffle	51%	0.336	1.837	0.05202	0.040349924	1.38
4x2 with baffle	54%	0.336	1.877	0.05315	0.040296719	1.36
4x2 with baffle	25%	0.336	2.342	0.06632	0.040588184	1.12
4x2 with baffle	29%	0.336	2.381	0.06742	0.040429555	1.10
4x2 with baffle	25%	0.336	2.435	0.06895	0.040403035	1.07
4x2 with baffle	99%	0.545	0.250	0.00708	0.066526143	15.19
4x2 with baffle	100%	0.545	0.295	0.00835	0.066275241	12.80
4x2 with baffle	100%	0.545	0.393	0.01113	0.066581516	9.78
4x2 with baffle	100%	0.545	0.492	0.01393	0.066442822	7.87
4x2 with baffle	101%	0.545	0.593	0.01679	0.06633124	6.53
4x2 with baffle	99%	0.545	0.611	0.01730	0.066387101	6.37
4x2 with baffle	102%	0.545	0.623	0.01764	0.066106408	6.21
4x2 with baffle	104%	0.545	1.167	0.03304	0.065331144	3.40
4x2 with baffle	98%	0.545	1.181	0.03344	0.066078147	3.42
4x2 with baffle	105%	0.545	1.307	0.03701	0.065389442	3.04
4x2 with baffle	78%	0.545	1.784	0.05052	0.065476627	2.31
4x2 with baffle	87%	0.545	1.837	0.05202	0.065650058	2.25
4x2 with baffle	85%	0.545	1.877	0.05315	0.065592387	2.21
4x2 with baffle	67%	0.550	2.342	0.06632	0.066478493	1.83
4x2 with baffle	63%	0.550	2.381	0.06742	0.066306892	1.81
4x2 with baffle	58%	0.550	2.435	0.06895	0.066278169	1.75
6x3 with baffle	12%	0.107	1.868	0.05290	0.003884381	0.15
6x3 with baffle	13%	0.107	1.869	0.05292	0.0040117	0.16
6x3 with baffle	15%	0.107	1.892	0.05358	0.003867264	0.15
6x3 with baffle	4%	0.107	3.379	0.09568	0.003943146	0.09
6x3 with baffle	4%	0.107	3.517	0.09959	0.003883111	0.09
6x3 with baffle	3%	0.107	3.649	0.10333	0.003878035	0.08
6x3 with baffle	3%	0.107	5.144	0.14566	0.003994801	0.06
6x3 with baffle	3%	0.107	5.284	0.14963	0.00403388	0.06
6x3 with baffle	3%	0.107	5.376	0.15223	0.004016911	0.06
6x3 with baffle	1%	0.107	7.058	0.19986	0.0040117	0.05
6x3 with baffle	1%	0.107	7.142	0.20224	0.004020822	0.05
6x3 with baffle	71%	0.336	1.868	0.05290	0.028707654	1.13
6x3 with baffle	75%	0.336	1.869	0.05292	0.029321174	1.15
6x3 with baffle	76%	0.336	1.892	0.05358	0.028624115	1.11
6x3 with baffle	37%	0.336	3.379	0.09568	0.028992543	0.67
6x3 with baffle	33%	0.336	3.517	0.09959	0.028701465	0.64
6x3 with baffle	32%	0.336	3.649	0.10333	0.028676709	0.62
6x3 with baffle	14%	0.336	5.144	0.14566	0.029240532	0.47
6x3 with baffle	18%	0.336	5.284	0.14963	0.029426656	0.46
6x3 with baffle	16%	0.336	5.376	0.15223	0.02934599	0.46
6x3 with baffle	6%	0.336	7.058	0.19986	0.029321174	0.36
6x3 with baffle	6%	0.336	7.142	0.20224	0.029364604	0.35
6x3 with baffle	100%	0.545	0.255	0.00722	0.053168579	13.54
6x3 with baffle	100%	0.545	0.408	0.01155	0.053027155	8.59

Sump Size	Removal Efficiency (%)	Particle Size (mm)	Flowrate (cfs)	Flowrate (m3/s)	Settling Velocity (m/s)	Peclet Number (-)
6x3 with baffle	99%	0.545	0.973	0.02755	0.052775174	3.75
6x3 with baffle	86%	0.545	1.868	0.05290	0.051959477	2.05
6x3 with baffle	93%	0.545	1.869	0.05292	0.052743627	2.07
6x3 with baffle	88%	0.545	1.892	0.05358	0.051852068	2.02
6x3 with baffle	42%	0.545	5.144	0.14566	0.052641023	0.85
6x3 with baffle	36%	0.545	5.284	0.14963	0.052877627	0.83
6x3 with baffle	44%	0.545	5.376	0.15223	0.052775174	0.82
6x3 with baffle	19%	0.545	7.058	0.19986	0.052743627	0.65
6x3 with baffle	19%	0.545	7.142	0.20224	0.052798827	0.64
6x3 with baffle	65%	0.550	3.379	0.09568	0.052873727	1.23
6x3 with baffle	62%	0.550	3.517	0.09959	0.052499504	1.17
6x3 with baffle	63%	0.550	3.649	0.10333	0.052467591	1.13